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Kalki et al.

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(54) **STATISTICAL DATA QUALITY DETERMINATION FOR STORAGE SYSTEMS**

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G06F 17/30 (2006.01)

(52) **U.S. Cl.**
CPC ***G06F 17/30371*** (2013.01)

(58) **Field of Classification Search**
CPC G06F 17/246; G06F 17/30336
USPC 707/694
See application file for complete search history.

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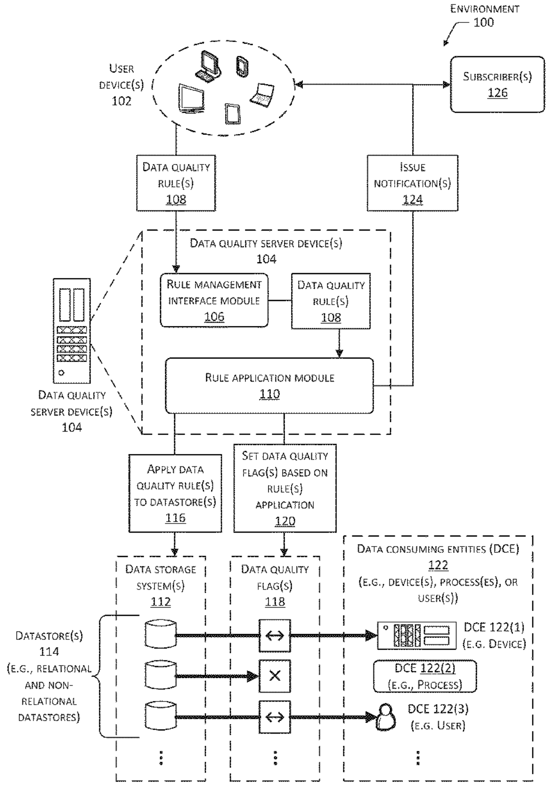
(57) **ABSTRACT**

Techniques are described for enabling or suspending access to one or more datastores based on a determined quality of the stored data. The datastores may use relational or non-relational formats. User-specified rules may be applied to statistically determine the data quality of at least a portion of the data in the datastore. The rules may perform statistical tests on the data, such as determining whether an amount of stored data is within a margin of a historical average, whether a number of records storing particular data is within a historical average, and so forth. Based on the rules, a flag may be set to indicate the determined data quality. Access to the data may be based on the value of the flag.

20 Claims, 10 Drawing Sheets


ENVIRONMENT
100
USER DEVICE(S)
102
SUBSCRIBER(S)
126
DATA QUALITY RULE(S)
108
ISSUE NOTIFICATION(S)
124
DATA QUALITY SERVER DEVICE(S)
104
RULE MANAGEMENT INTERFACE MODULE
106
DATA QUALITY RULE(S)
108
RULE APPLICATION MODULE
110
DATA QUALITY SERVER DEVICE(S)
104
APPLY DATA QUALITY RULE(S) TO DATASTORE(S)
116
SET DATA QUALITY FLAG(S) BASED ON RULE(S) APPLICATION
120
DATA STORAGE SYSTEM(S)
112
DATA QUALITY FLAG(S)
118
DATA CONSUMING ENTITIES (DCE)
122
(E.G., DEVICE(S), PROCESS(ES), OR USER(S))
DATASTORE(S)
114
(E.G., RELATIONAL AND NON-RELATIONAL DATASTORES)
DCE 122(1)
(E.G. DEVICE)
DCE 122(2)
(E.G., PROCESS)
DCE 122(3)
(E.G. USER)

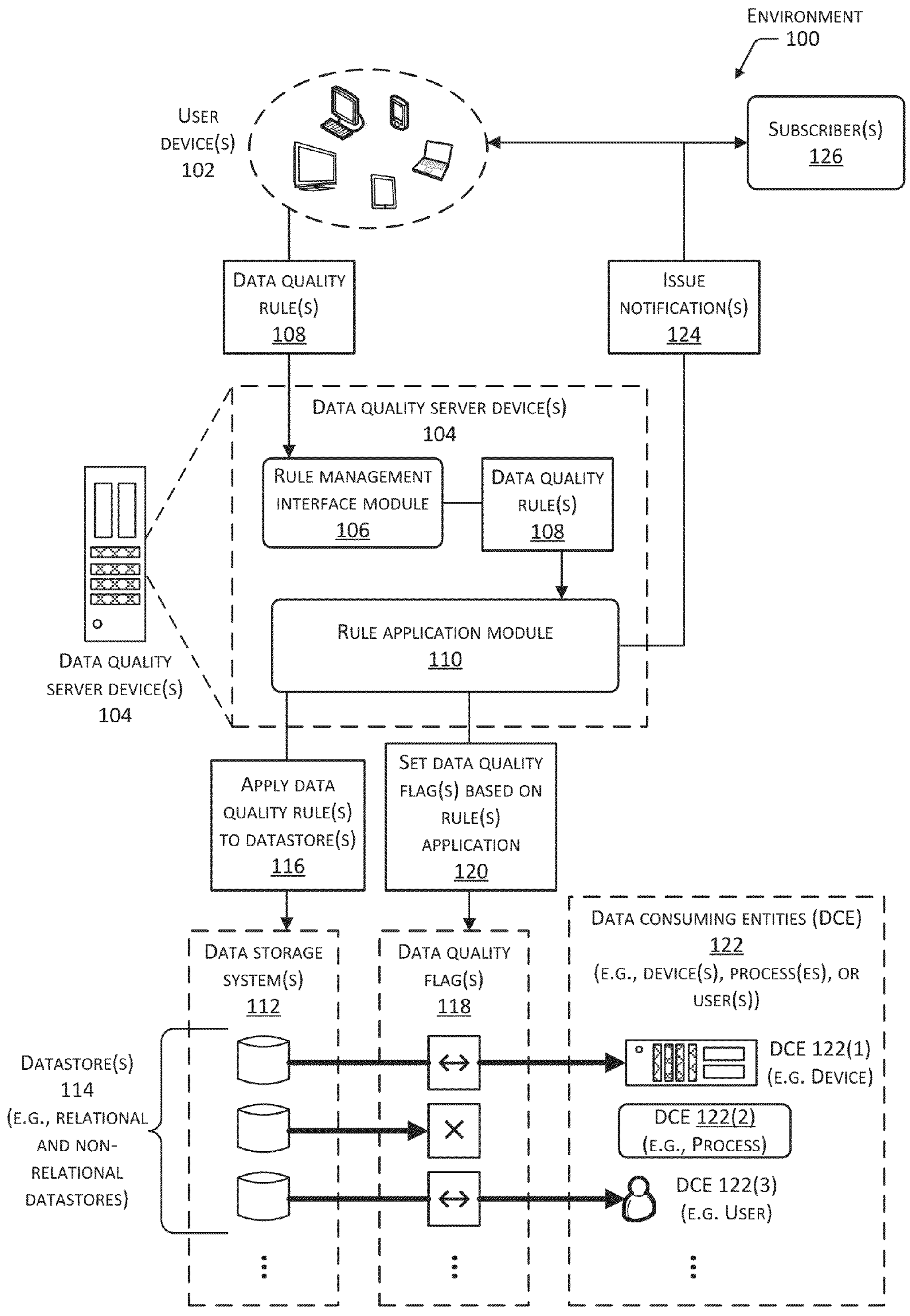

Environment
100
User device(s)
102
Subscriber(s)
126
Data quality rule(s)
108
Issue notification(s)
124
Data quality server device(s)
104
Rule management interface module
106
Data quality rule(s)
108
Rule application module
110
Data quality server device(s)
104
Apply data quality rule(s) to datastore(s)
116
Set data quality flag(s) based on rule(s) application
120
Data storage system(s)
112
Data quality flag(s)
118
Data consuming entities (DCE)
122
(e.g., device(s), process(es), or user(s))
Datastore(s)
114
(e.g., relational and non-relational datastores)
DCE 122(1)
(e.g. Device)
DCE 122(2)
(e.g., Process)
DCE 122(3)
(e.g. User)

FIG. 1

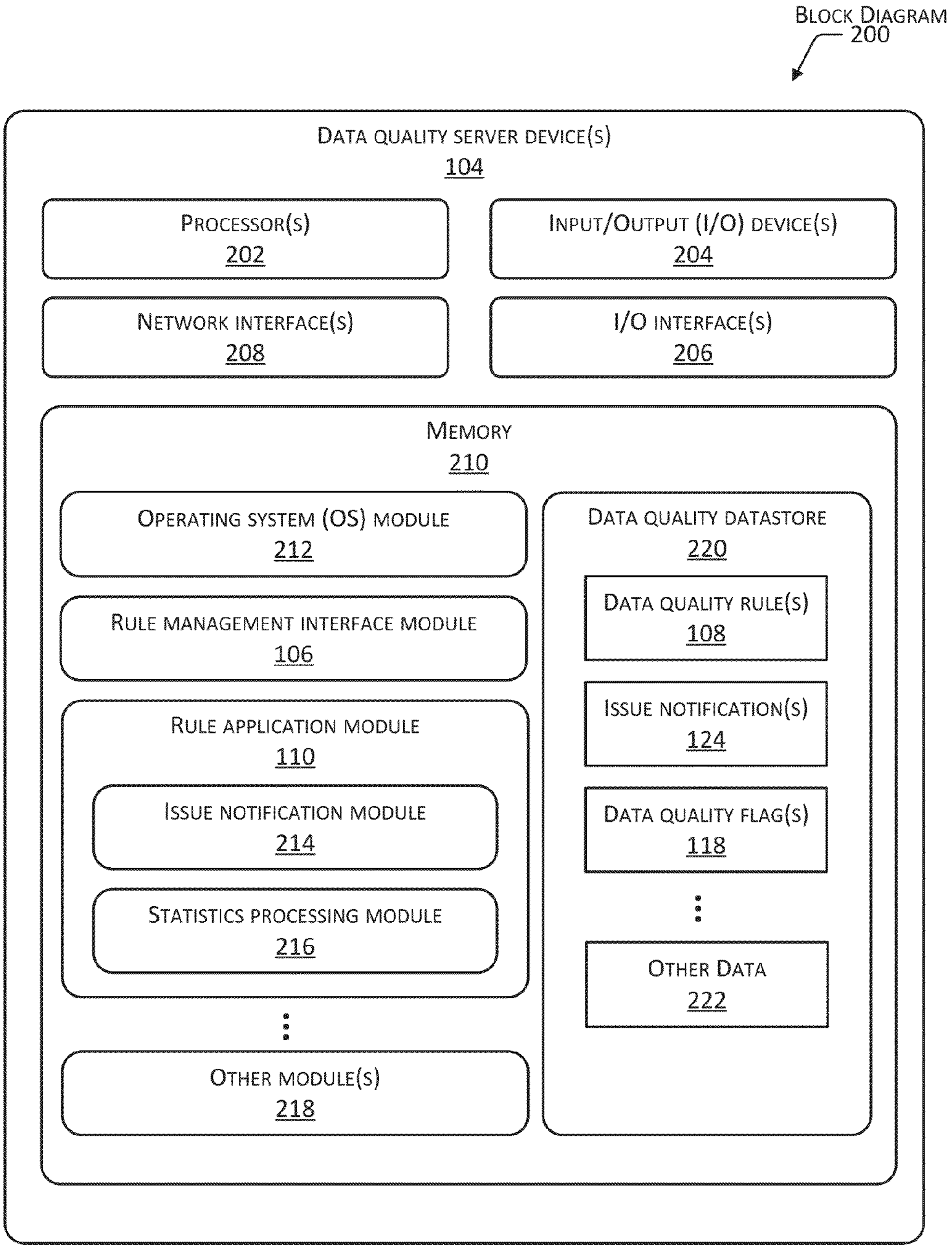

Block Diagram
200
Data quality server device(s)
104
Processor(s)
202
Input/Output (I/O) device(s)
204
Network interface(s)
208
I/O interface(s)
206
Memory
210
Operating system (OS) module
212
Rule management interface module
106
Rule application module
110
Issue notification module
214
Statistics processing module
216
Other module(s)
218
Data quality datastore
220
Data quality rule(s)
108
Issue notification(s)
124
Data quality flag(s)
118
Other Data
222

FIG. 2

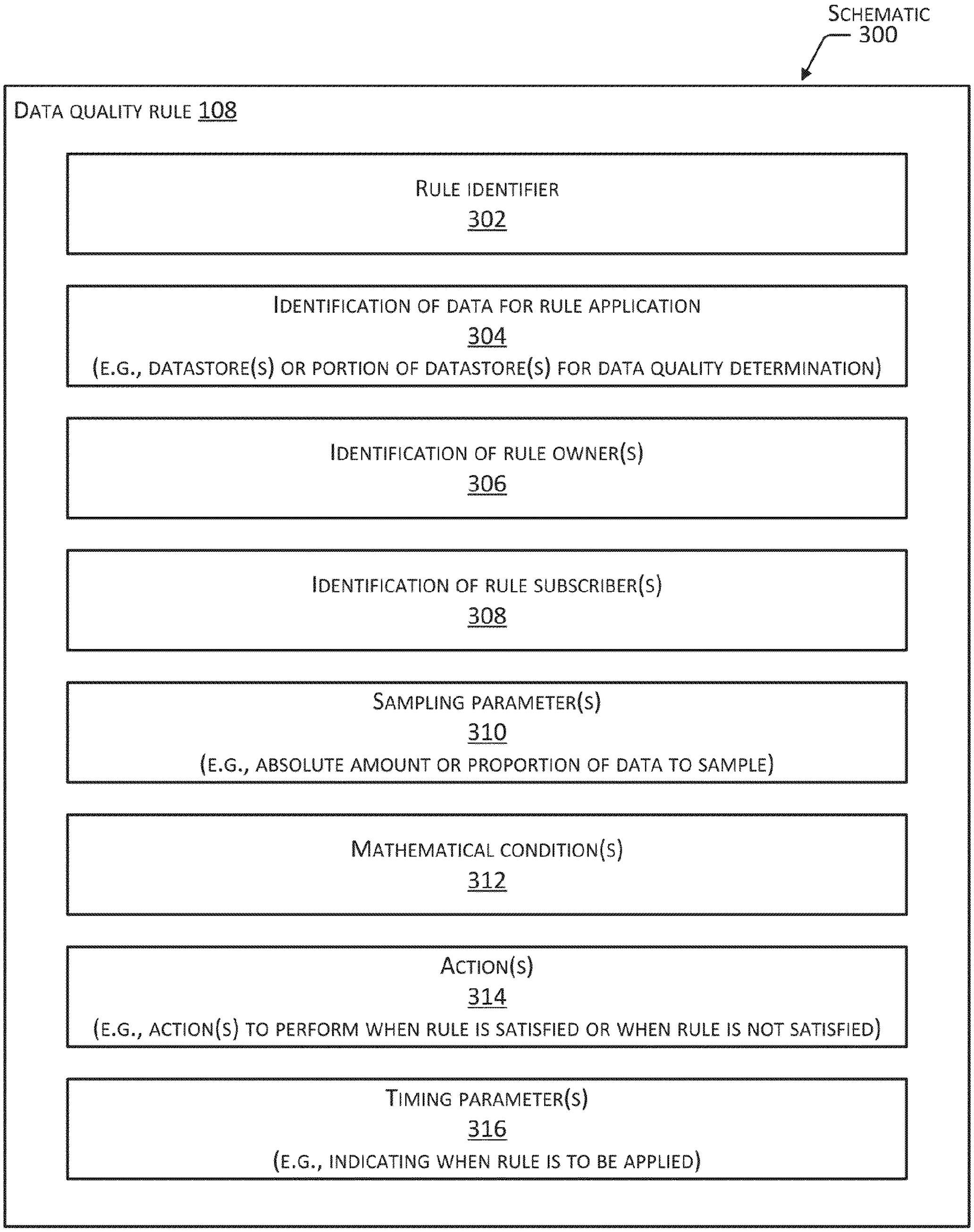

SCHEMATIC 300
DATA QUALITY RULE 108
RULE IDENTIFIER 302
IDENTIFICATION OF DATA FOR RULE APPLICATION 304 (E.G., DATASTORE(S) OR PORTION OF DATASTORE(S) FOR DATA QUALITY DETERMINATION)
IDENTIFICATION OF RULE OWNER(S) 306
IDENTIFICATION OF RULE SUBSCRIBER(S) 308
SAMPLING PARAMETER(S) 310 (E.G., ABSOLUTE AMOUNT OR PROPORTION OF DATA TO SAMPLE)
MATHEMATICAL CONDITION(S) 312
ACTION(S) 314 (E.G., ACTION(S) TO PERFORM WHEN RULE IS SATISFIED OR WHEN RULE IS NOT SATISFIED)
TIMING PARAMETER(S) 316 (E.G., INDICATING WHEN RULE IS TO BE APPLIED)

FIG. 3

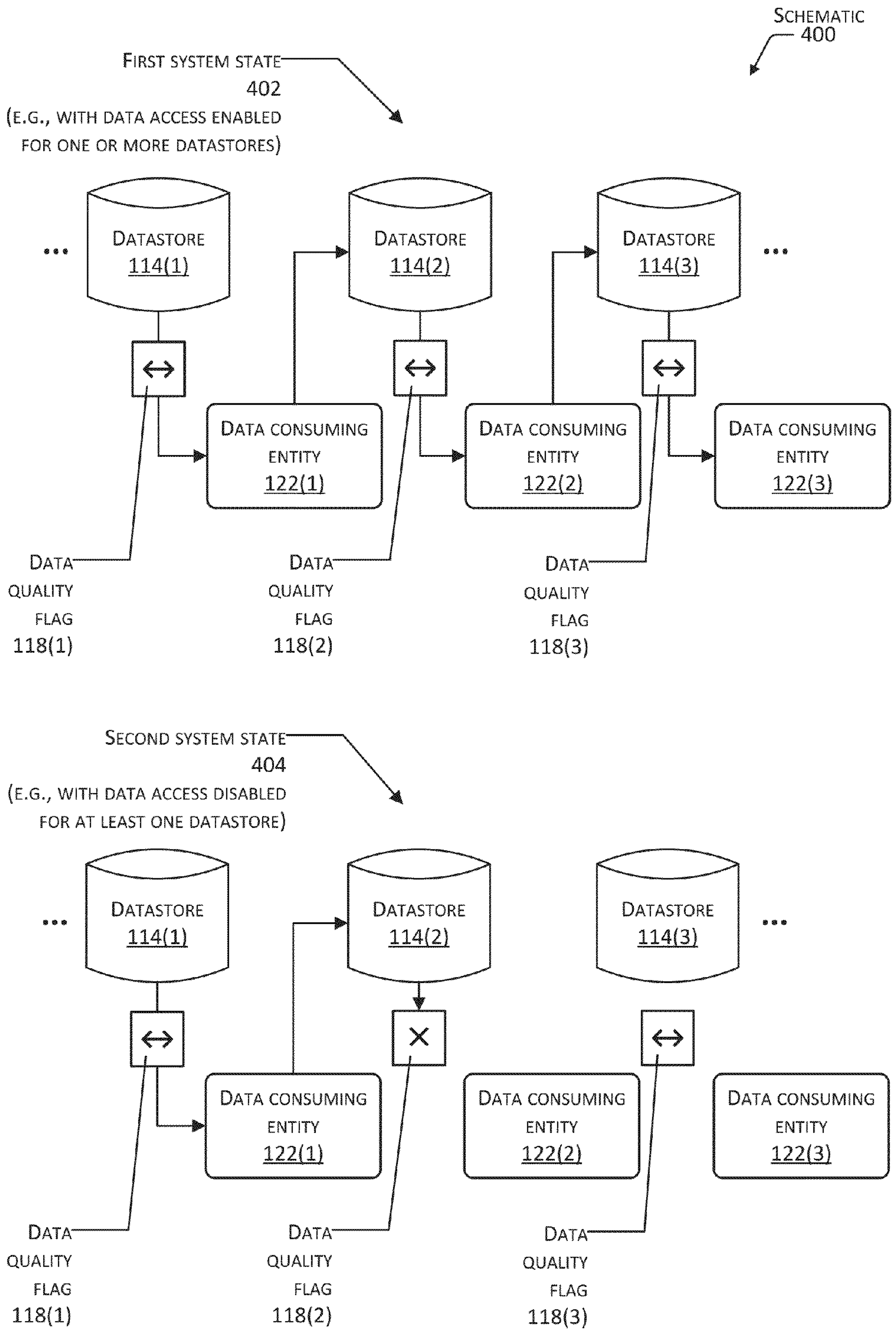

SCHEMATIC
400
FIRST SYSTEM STATE
402
(E.G., WITH DATA ACCESS ENABLED FOR ONE OR MORE DATASTORES)
...
DATASTORE
114(1)
DATASTORE
114(2)
DATASTORE
114(3)
...
DATA CONSUMING ENTITY
122(1)
DATA CONSUMING ENTITY
122(2)
DATA CONSUMING ENTITY
122(3)
DATA QUALITY FLAG
118(1)
DATA QUALITY FLAG
118(2)
DATA QUALITY FLAG
118(3)
SECOND SYSTEM STATE
404
(E.G., WITH DATA ACCESS DISABLED FOR AT LEAST ONE DATASTORE)
...
DATASTORE
114(1)
DATASTORE
114(2)
DATASTORE
114(3)
...
DATA CONSUMING ENTITY
122(1)
DATA CONSUMING ENTITY
122(2)
DATA CONSUMING ENTITY
122(3)
DATA QUALITY FLAG
118(1)
DATA QUALITY FLAG
118(2)
DATA QUALITY FLAG
118(3)

FIG. 4

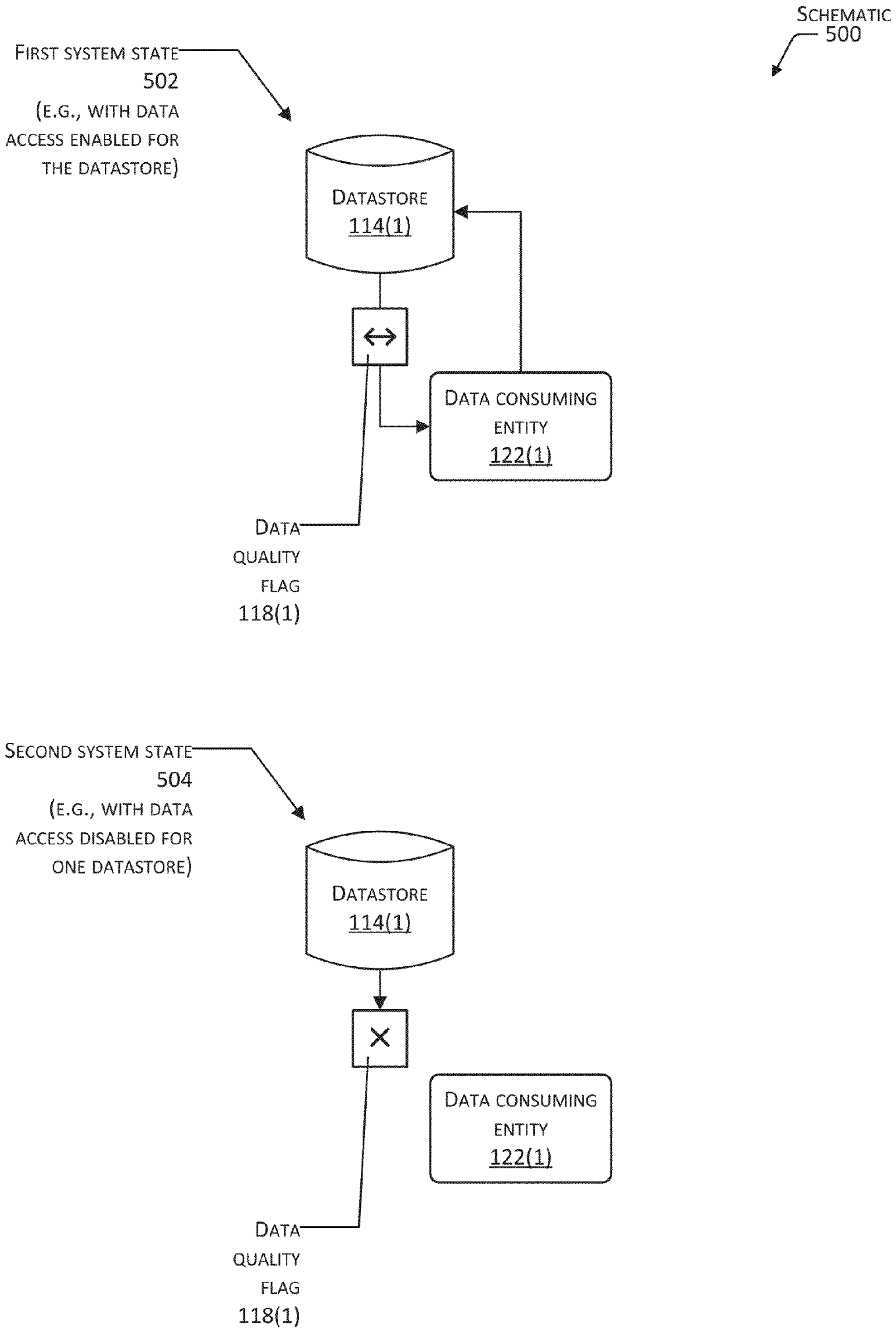

SCHEMATIC
500
FIRST SYSTEM STATE
502
(E.G., WITH DATA
ACCESS ENABLED FOR
THE DATASTORE)
DATASTORE
114(1)
DATA CONSUMING
ENTITY
122(1)
DATA
QUALITY
FLAG
118(1)
SECOND SYSTEM STATE
504
(E.G., WITH DATA
ACCESS DISABLED FOR
ONE DATASTORE)
DATASTORE
114(1)
DATA CONSUMING
ENTITY
122(1)
DATA
QUALITY
FLAG
118(1)

FIG. 5

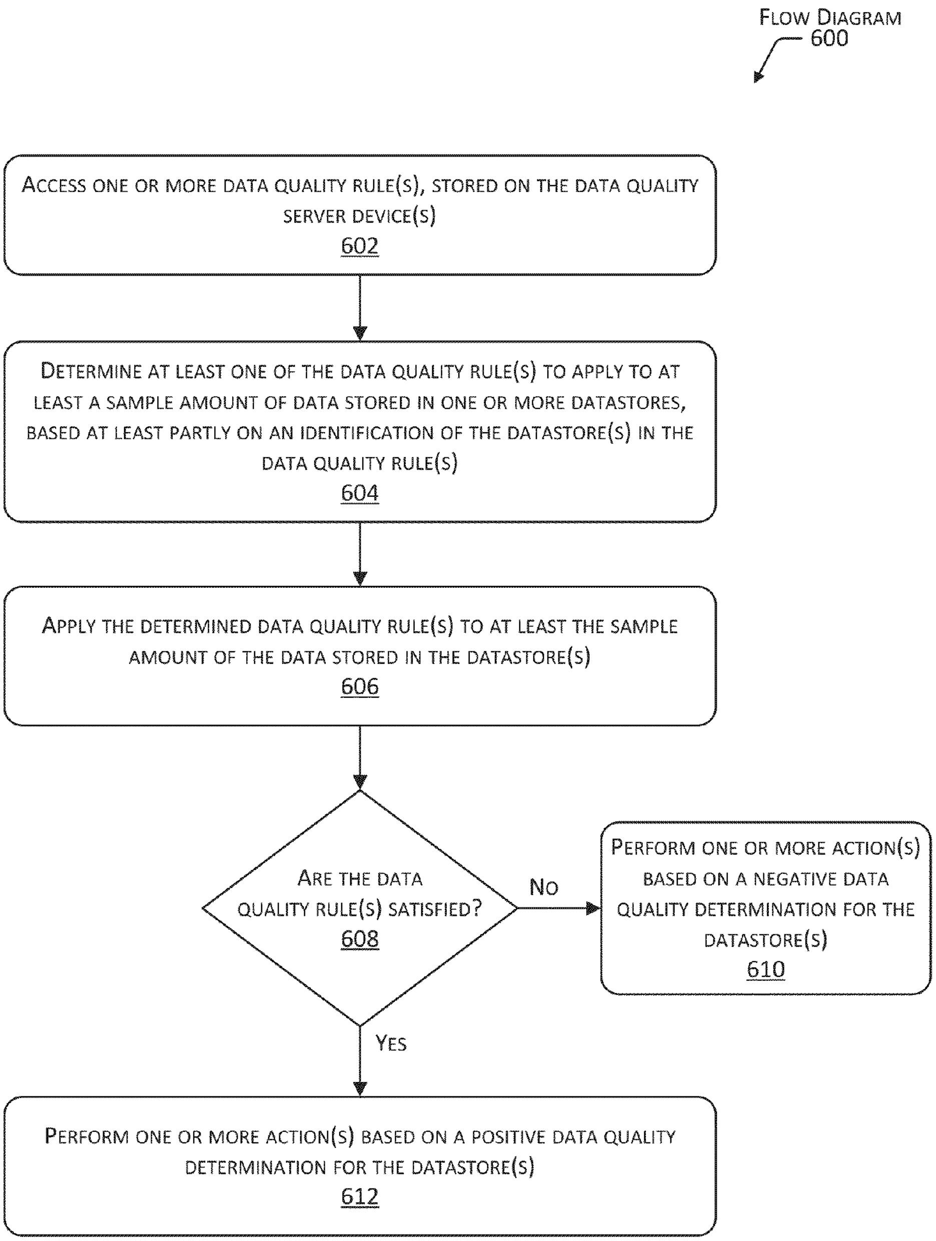

Flow Diagram
600
Access one or more data quality rule(s), stored on the data quality server device(s)
602
Determine at least one of the data quality rule(s) to apply to at least a sample amount of data stored in one or more datastores, based at least partly on an identification of the datastore(s) in the data quality rule(s)
604
Apply the determined data quality rule(s) to at least the sample amount of the data stored in the datastore(s)
606
Are the data quality rule(s) satisfied?
608
No
Perform one or more action(s) based on a negative data quality determination for the datastore(s)
610
Yes
Perform one or more action(s) based on a positive data quality determination for the datastore(s)
612

FIG. 6

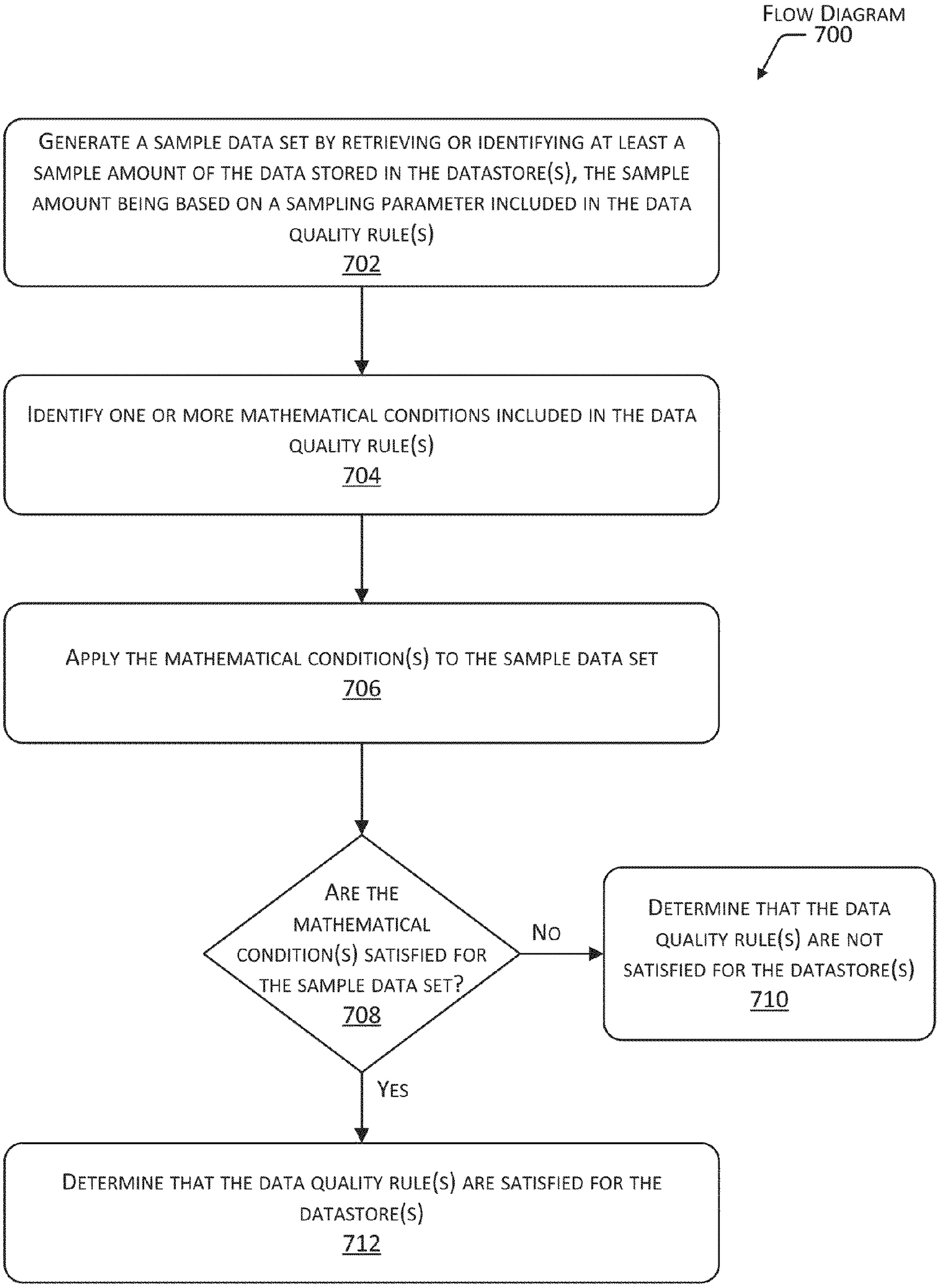

FLOW DIAGRAM
700
GENERATE A SAMPLE DATA SET BY RETRIEVING OR IDENTIFYING AT LEAST A SAMPLE AMOUNT OF THE DATA STORED IN THE DATASTORE(S), THE SAMPLE AMOUNT BEING BASED ON A SAMPLING PARAMETER INCLUDED IN THE DATA QUALITY RULE(S)
702
IDENTIFY ONE OR MORE MATHEMATICAL CONDITIONS INCLUDED IN THE DATA QUALITY RULE(S)
704
APPLY THE MATHEMATICAL CONDITION(S) TO THE SAMPLE DATA SET
706
ARE THE MATHEMATICAL CONDITION(S) SATISFIED FOR THE SAMPLE DATA SET?
708
NO
DETERMINE THAT THE DATA QUALITY RULE(S) ARE NOT SATISFIED FOR THE DATASTORE(S)
710
YES
DETERMINE THAT THE DATA QUALITY RULE(S) ARE SATISFIED FOR THE DATASTORE(S)
712

FIG. 7

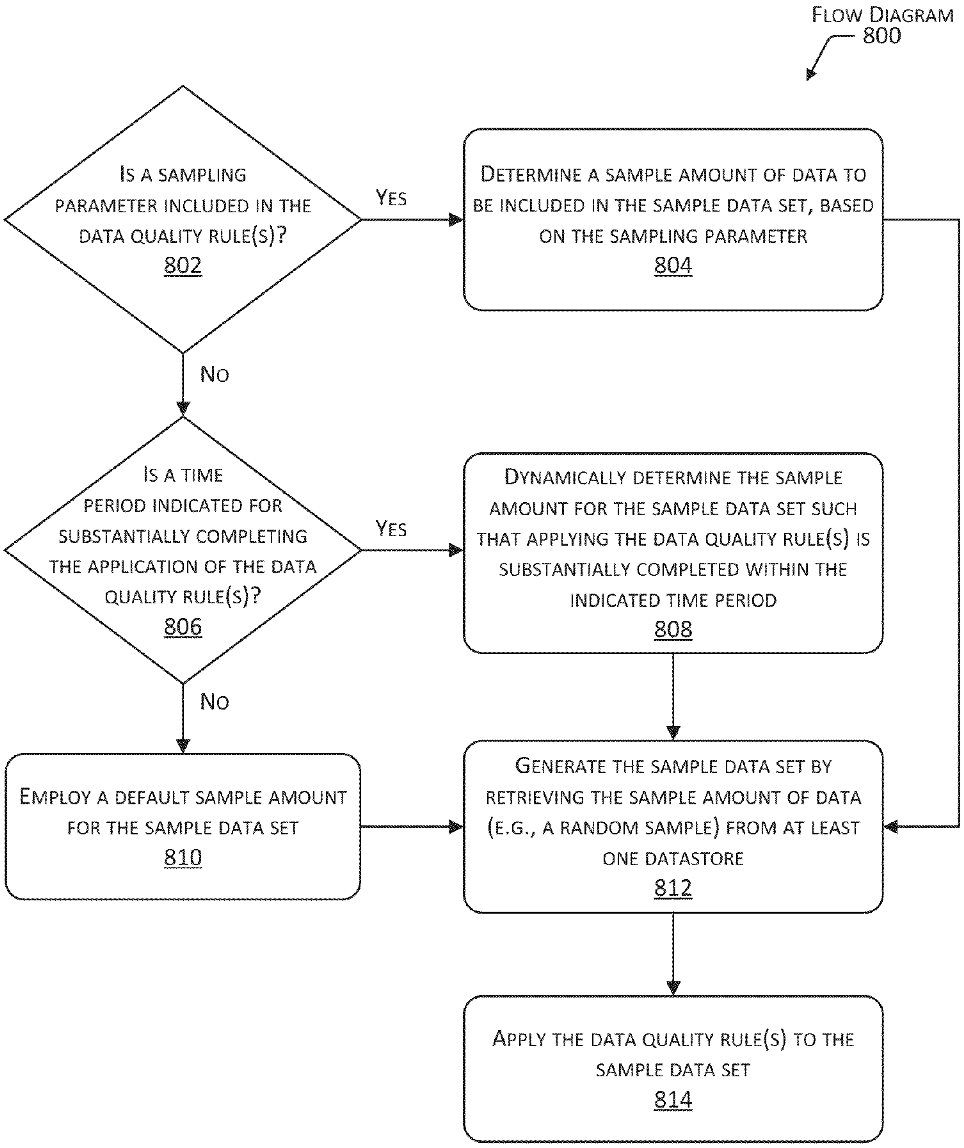

Flow Diagram
800
Is a sampling parameter included in the data quality rule(s)?
802
Yes
Determine a sample amount of data to be included in the sample data set, based on the sampling parameter
804
No
Is a time period indicated for substantially completing the application of the data quality rule(s)?
806
Yes
Dynamically determine the sample amount for the sample data set such that applying the data quality rule(s) is substantially completed within the indicated time period
808
No
Employ a default sample amount for the sample data set
810
Generate the sample data set by retrieving the sample amount of data (e.g., a random sample) from at least one datastore
812
Apply the data quality rule(s) to the sample data set
814

FIG. 8

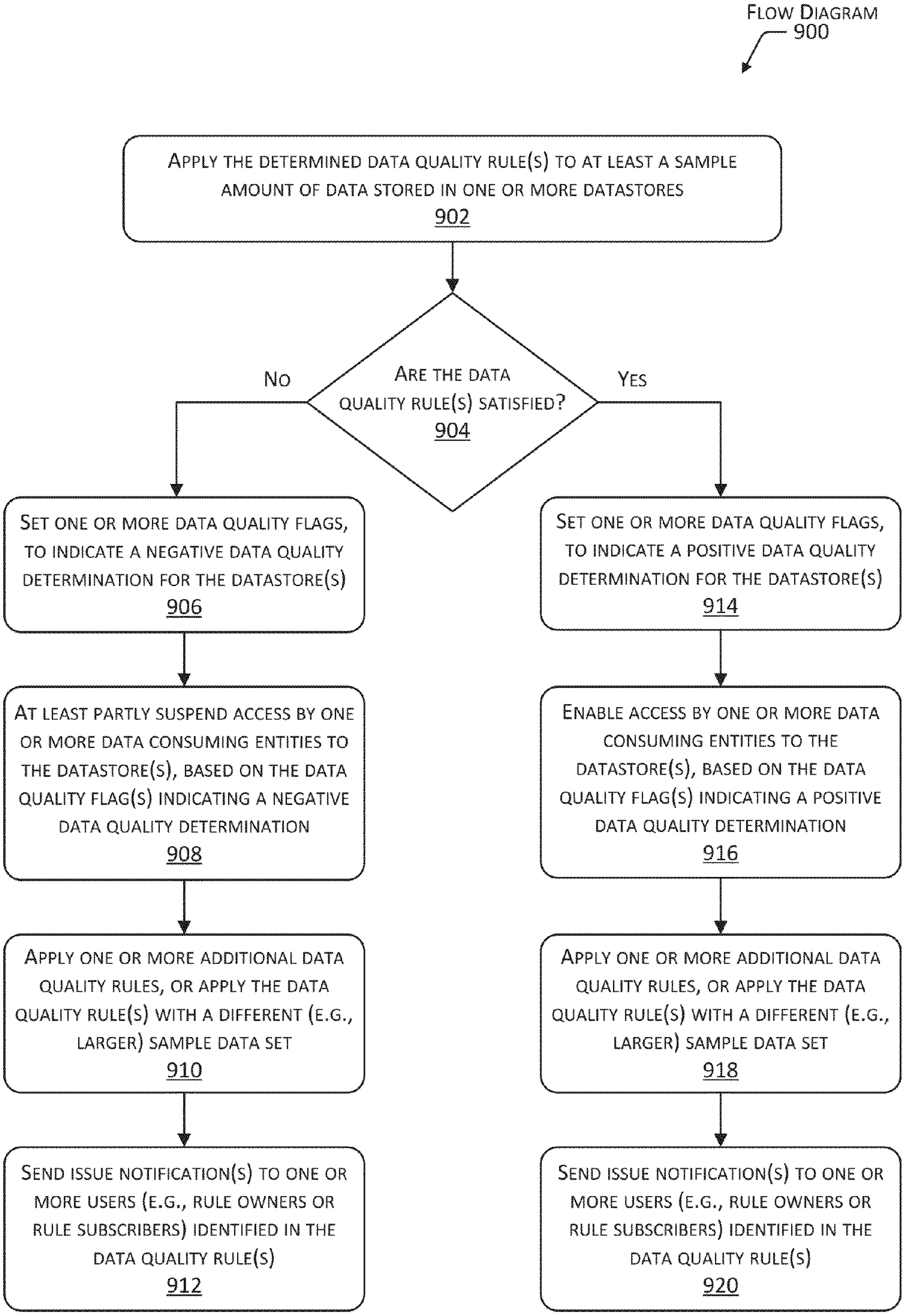

FLOW DIAGRAM
900
APPLY THE DETERMINED DATA QUALITY RULE(S) TO AT LEAST A SAMPLE AMOUNT OF DATA STORED IN ONE OR MORE DATASTORES
902
ARE THE DATA QUALITY RULE(S) SATISFIED?
904
NO
YES
SET ONE OR MORE DATA QUALITY FLAGS, TO INDICATE A NEGATIVE DATA QUALITY DETERMINATION FOR THE DATASTORE(S)
906
AT LEAST PARTLY SUSPEND ACCESS BY ONE OR MORE DATA CONSUMING ENTITIES TO THE DATASTORE(S), BASED ON THE DATA QUALITY FLAG(S) INDICATING A NEGATIVE DATA QUALITY DETERMINATION
908
APPLY ONE OR MORE ADDITIONAL DATA QUALITY RULES, OR APPLY THE DATA QUALITY RULE(S) WITH A DIFFERENT (E.G., LARGER) SAMPLE DATA SET
910
SEND ISSUE NOTIFICATION(S) TO ONE OR MORE USERS (E.G., RULE OWNERS OR RULE SUBSCRIBERS) IDENTIFIED IN THE DATA QUALITY RULE(S)
912
SET ONE OR MORE DATA QUALITY FLAGS, TO INDICATE A POSITIVE DATA QUALITY DETERMINATION FOR THE DATASTORE(S)
914
ENABLE ACCESS BY ONE OR MORE DATA CONSUMING ENTITIES TO THE DATASTORE(S), BASED ON THE DATA QUALITY FLAG(S) INDICATING A POSITIVE DATA QUALITY DETERMINATION
916
APPLY ONE OR MORE ADDITIONAL DATA QUALITY RULES, OR APPLY THE DATA QUALITY RULE(S) WITH A DIFFERENT (E.G., LARGER) SAMPLE DATA SET
918
SEND ISSUE NOTIFICATION(S) TO ONE OR MORE USERS (E.G., RULE OWNERS OR RULE SUBSCRIBERS) IDENTIFIED IN THE DATA QUALITY RULE(S)
920

FIG. 9

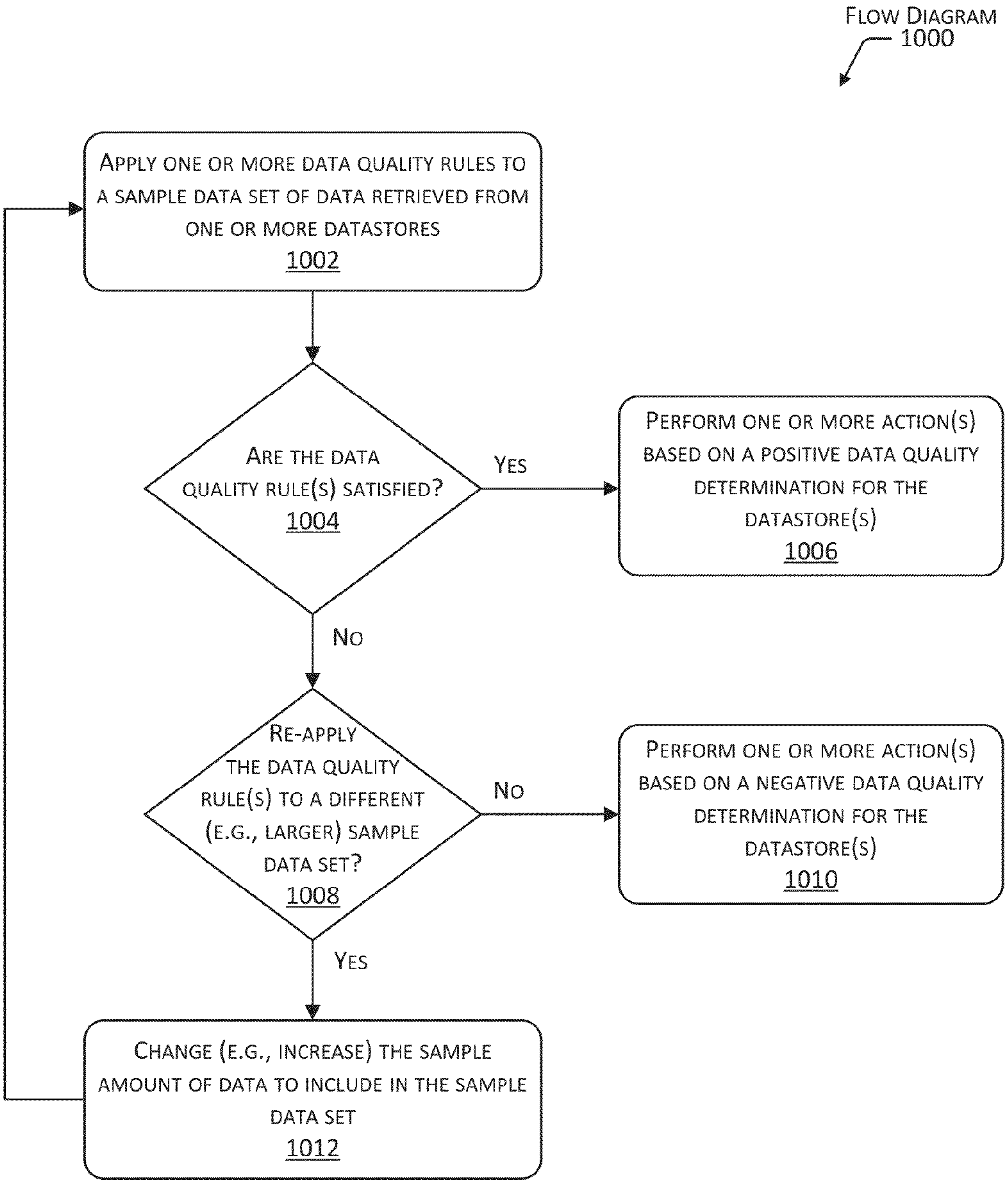

FLOW DIAGRAM
1000
APPLY ONE OR MORE DATA QUALITY RULES TO A SAMPLE DATA SET OF DATA RETRIEVED FROM ONE OR MORE DATASTORES
1002
ARE THE DATA QUALITY RULE(S) SATISFIED?
1004
YES
PERFORM ONE OR MORE ACTION(S) BASED ON A POSITIVE DATA QUALITY DETERMINATION FOR THE DATASTORE(S)
1006
NO
RE-APPLY THE DATA QUALITY RULE(S) TO A DIFFERENT (E.G., LARGER) SAMPLE DATA SET?
1008
NO
PERFORM ONE OR MORE ACTION(S) BASED ON A NEGATIVE DATA QUALITY DETERMINATION FOR THE DATASTORE(S)
1010
YES
CHANGE (E.G., INCREASE) THE SAMPLE AMOUNT OF DATA TO INCLUDE IN THE SAMPLE DATA SET
1012

FIG. 10

STATISTICAL DATA QUALITY DETERMINATION FOR STORAGE SYSTEMS

BACKGROUND

Commercial enterprises and other organizations often store large amounts of data related to their operations. For example, an online business may store terabytes, petabytes, exabytes, or more of data describing products, sale transactions, customers, vendors, online activities of customers, and so forth. In some cases, data produced by one group, process, or individual in an organization may be consumed by various other groups, processes, or individuals in the organization. In such cases, corrupted, incomplete, or otherwise low quality data produced in one part of the organization may cause problems elsewhere in the organization.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** depicts an environment for determining data quality of data stored in one or more datastores, including one or more user devices for providing one or more data quality rules, and one or more data quality server devices for applying the data quality rule(s) to evaluate a data quality of the data stored in the datastore(s).

FIG. **2** depicts a block diagram of an example data quality server device configured to perform operations for determining data quality through the application of the data quality rule(s).

FIG. **3** depicts a schematic of an example data structure for the data quality rule(s).

FIG. **4** depicts the enabling and disabling of access to a plurality of datastores through the use of one or more flags that indicate data quality of the datastore(s), in a scenario where there is a linear data flow between the datastores.

FIG. **5** depicts the enabling and disabling of access to a datastore through the use of a flag that indicates data quality of the datastore, in a scenario where there is a cyclic data flow to and from the datastore.

FIG. **6** depicts a flow diagram of a process for applying one or more data quality rules to data stored in one or more datastores, and performing one or more actions based on the results of the application of the data quality rule(s).

FIG. **7** depicts a flow diagram of a process for applying one or more data quality rules to data stored in the datastores(s), including generating a sample data set and applying one or more mathematical conditions to the sample data set to determine whether the data quality rule(s) are satisfied.

FIG. **8** depicts a flow diagram of a process for determining a sample set of data for applying the data quality rule(s).

FIG. **9** depicts a flow diagram of a process for performing one or more actions based on the results of applying the data quality rule(s).

FIG. **10** depicts a flow diagram of a process for iteratively applying the data quality rule(s) to sample data sets of varying sizes, based on the results of one or more previous applications of the data quality rule(s).

Certain implementations and embodiments will now be described more fully below with reference to the accompanying figures, in which various aspects are shown. However, various aspects may be implemented in many different forms and should not be construed as limited to the implementations set forth herein. Like numbers refer to like elements throughout.

DETAILED DESCRIPTION

This disclosure describes implementations of systems, devices, methods, and computer-readable media for determining data quality of data stored in one or more datastores, and performing one or more actions based on the determined data quality. Implementations provide for the determination of data quality for one or more datastores, through the application of one or more data quality rules. For each datastore, a data quality flag may be set to indicate the data quality of the data stored in the datastore, based on the results of applying the data quality rules. Access to the data may be suspended or enabled based on a value of the data quality flag. In some cases, one or more issue notifications may be sent to notify users of the results of applying the data quality rules.

As used herein, a datastore describes a data storage system storing any type of data in any type of storage format, using any type of data storage technology. Implementations provide for data retrieval from datastores that include relational databases, such as databases that employ a relational database management system (RDBMS). Implementations also provide for data retrieval from datastores that employ a non-relational storage format, such as a "not only SQL" (NoSQL) database that does not adhere to a relational database model.

FIG. **1** depicts an environment **100** in which implementations may operate to determine data quality of data stored in one or more datastores, as described herein. In some implementations, the environment **100** includes one or more user device(s) **102**. In some cases, the user device(s) **102** may be employed by one or more data consumers to access, analyze, process, update, or otherwise use data stored in one or more datastores. The user device(s) **102** may also be employed by one or more data producers to generate, update, or store data stored in one or more datastores. Other users such as system administrators may also employ the user device(s) **102**.

As used herein, data consumers and data producers may include individuals, processes, devices, or any groups of individuals, processes, or devices. In some cases, data consumers or data producers may be associated with a business or other type of organization. The data consumers may consume data for any purpose, such as to develop processes, systems, services, or products, to analyze or improve business or organizational operations, or for other purposes. The data producers may generate and store data associated with the operation of the business or organization, including data related to products, services, customers, billings, or other types of data. In some cases, one or more individuals, processes, or devices may operate as both data consumers and data producers.

In implementations, the user device(s) **102** may communicate with one or more data quality server device(s) **104**. The user device(s) **102** and the data quality server device(s) **104** may include any type of computing device, including but not limited to a smartphone, a personal data assistant (PDA), a tablet computer, a wearable computer, an implanted computer, a mobile gaming device, an electronic book reader, an automotive computer, a desktop computer, a personal computer, a laptop computer, a thin client, a terminal, a game console, a smart appliance, a home entertainment device, a mainframe computer, a server computer, a network computer, and so forth. An example of the data quality server device(s) **104** is described further with reference to FIG. **2**.

In some implementations, the data quality server device(s) **104** execute a rule management interface module **106**. The rule management interface module **106** may provide a user interface to enable user(s) of the user device(s) **102** to define and provide one or more data quality rule(s) **108**. The user(s) who define and provide the data quality rule(s) **108** may be described as author(s) of the data quality rule(s) **108**.

The user interface may be a graphical user interface, command-line user interface, or any other type of user interface. In some cases, the rule management interface module **106** may provide the user interface through one or more web pages, and the user device(s) **102** may access the user interface by executing a web browser such as Mozilla® Firefox®, Microsoft® Internet Explorer®, Google® Chrome®, Apple® Safari®, Rockmelt®, and so forth. In such cases, the data quality rule(s) **108** or other information may be sent via a web browser-supported communications protocol, such as the Hypertext Transfer Protocol (HTTP), the HTTP Secure (HTTPS), the File Transfer Protocol (FTP), and so forth.

In some implementations, the communications between the user device(s) **102** and the data quality server device(s) **104**, or between other devices in the environment **100**, may be secure or encrypted. For example, the communications may be encrypted using any version of the Secure Sockets Layer (SSL) protocol or the Transport Layer Security (TLS) protocol.

The data quality rule(s) **108** may include one or more rules or sets of rules to be applied to determine data quality of data stored in one or more datastores. The data quality rule(s) **108** may be configurable by users such as data producers, data consumers, data storage administrators, or others. In some cases, the data quality rule(s) **108** may be expressed in a structured data format that includes descriptive metadata. For example, the data quality rule(s) **108** may be expressed using a version of the Extensible Markup Language (XML), or another markup language.

In some implementations, the data quality rule(s) **108** may include one or more conditions to be applied to data stored in one or more datastores. The conditions may include mathematical or statistical conditions on the data. For example, one of the data quality rule(s) **108** may include a mathematical condition to test whether a current amount of data stored in a particular table or other portion of a datastore is within a predetermined margin (e.g., 5%) of a historical average for the amount of data stored. In cases where the current amount of data is above or below the predetermined margin, the data quality rule **108** may fail. The data quality rule(s) **108** may include a timing parameter specifying one or more start times when the data quality rules(s) **108** are to be executed. The data quality rule(s) **108** may also include an identification of the datastore(s) to which the data quality rule(s) **108** are to be applied, and a sampling parameter specifying a sample amount of the stored data to be tested or evaluated during an application of the data quality rule(s) **108**. The data quality rule(s) **108** are described further with reference to FIG. **3**.

In some cases, the rule management interface module **106**, or another module of the data quality server device(s) **104**, may receive the data quality rule(s) **108** provided by a user and perform an analysis to determine whether the received data quality rule(s) **108** are identical or substantially similar to previously received rules. If so, the user may be prompted to subscribe to one or more of the previously received rules, and receive a notification of the results of subsequent applications of such rules.

In some implementations, the rule management interface module **106** may provide the data quality rule(s) **108** to a rule application module **110** executing on the data quality server device(s) **104**. The rule application module **110** may communicate with one or more data storage systems **112** that each includes one or more datastores **114**. The rule application module **110** may perform one or more operations to apply data quality rule(s) to datastores **116** to determine data quality of data stored in the datastore(s) **114**. Operations of the rule application module **110** are described further herein, with reference to FIGS. **4-10**.

The datastore(s) **114** in the data storage system(s) **112** may include any number of databases, data storage nodes, or other data storage devices. In some cases, the datastore(s) **114** may include one or more processors or computing devices to perform actions for data storage, retrieval, and modification. Alternatively, the datastore(s) **114** may be controlled by processors or computing devices not included in the data storage system(s) **112**. The datastore(s) **114** may store any amount of structured or unstructured data. In some cases, the amount of data stored in the data storage system(s) **112** may be on the order of exabytes.

The datastore(s) **114** may include any number of relational datastores. As used herein, a relational datastore describes a datastore that employs a relational storage format including one or more formally described tables, each table including one or more columns associated with data attributes. In such cases, the datastore(s) **114** may be managed through RDBMS software. The datastore(s) **114** may include any number of relational databases, including but not limited to databases managed through any of the following: Oracle® and MySQL®, from Oracle Corporation of Redwood City, Calif.; DB2®, from International Business Machines (IBM) Corporation of Armonk, N.Y.; Linter®, from the RELEX Group of Voronezh, Russia; Microsoft Access® and Microsoft SQL Server®, from Microsoft Corporation of Redmond, Wash.; PostgreSQL®, from the PostgreSQL Global Development Group; and SQLite®, from D. Richard Hipp.

The datastore(s) **114** may also include any number of non-relational datastores. As used herein, a non-relational datastore describes a datastore that employs a non-relational data storage format and that may not comply with a relational database model. In some cases, non-relational datastores may employ a hierarchical database model, or a network database model. Non-relational datastores may also include key-value datastores, hash tables, flat files, associative arrays, other types of data structures, or unstructured data storage. In some cases, non-relational datastores may store metadata describing data attributes or other aspects of the stored data. Non-relational datastores may include any number of non-relational databases, including but not limited to databases managed through any of the following: FoxPro® database management system, from Microsoft Corporation of Redmond, Wash.; ParAccel® Analytic Database, from ParAccel, Incorporated of San Diego, Calif.; and Hadoop®, from the Apache Software Foundation.

In some cases, the datastore(s) **114** of the data storage system(s) **112** may store large amounts of data, on the order of petabytes, exa bytes, or greater. The datastores may be subject to a high frequency of updates, for example hundreds of millions of updates daily. In some implementations, the datastore(s) **114** in the data storage system(s) **112** may be owned by, operated by, controlled by, or otherwise associated with different individuals, groups of individuals, or organizations. For example, a datastore A may be associated with a particular group X within an organization, and a datastore B may be associated with a particular group Y within an organization, such that the data stored in datastores A and B originates from data producers associated with groups X and Y respectively.

Although the data storage system(s) **112** are depicted in FIG. **1** as including three datastores, implementations are not so limited. Implementations support any number of the data storage system(s) **112**, each including any number of the datastore(s) **114**. The datastore(s) **114** may include one or more relational datastores, one or more non-relational datastores, or both relational and non-relational datastores. Each of the datastore(s) **114** may support one or more native query languages for performing data read and write operations. For example, relational datastores may support a version of the

Structured Query Language (SQL). As another example, non-relational datastores may support queries in the Hadoop Query Language (HQL), MapReduce, or other query languages.

In some implementations, the environment **100** may include one or more indicators of data quality, such as one or more data quality flags **118**. The data quality flag(s) **118** or other indicia of data quality may be stored in computer memory as variables, data structures, or other portions of memory, storing any amount or type of data. In some cases, each of the datastore(s) **114** may be associated with one or more of the data quality flag(s) **118**, and a value stored in the data quality flag(s) **118** may indicate a quality of the data stored in the associated datastore(s) **114**. In some implementations, each of the data quality flag(s) **118** may be stored in the memory of an associated datastore **114**. Alternatively, the data quality flag(s) **118** may be stored in memory on the data quality server device(s) **104** or on one or more other devices. In some implementations, the data quality flags **118** may be arranged in memory as an array of key-value pairs. In such implementations, each key-value pair may include a key that identifies a datastore **114** and an associated value that is the data quality flag **118** indicating a data quality for the datastore **114**.

In some implementations, the data quality flag(s) **118** may each store one or more binary values indicating a positive data quality or a negative data quality of one or more associated datastores **114**. Although examples described herein provide for a binary (e.g., positive or negative) data quality, implementations support any number of values to indicate any level of granularity for the data quality of data stored in the datastore(s) **114**.

As described further herein, the rule application module **110** applies the data quality rule(s) **108** to test, evaluate, or otherwise determine the data quality of data stored in the datastore(s) **114**. The rule application module **110** may also perform one or more operations **120** to set a value of the data quality flag(s) **118** based on the determined data quality. In some implementations, the value of each data quality flag **118** determines whether one or more data consuming entities (DCE) **122** may access a datastore **114** that is associated with the data quality flag **118**. The one or more data consuming entities **122** may include one or more devices, one or more processes, or one or more users that may request access to the stored data.

In some implementations, if a data quality flag **118** is set to a value that indicates a negative data quality, access to an associated datastore **114** may be suspended such that the data consuming entities **122** may be prevented from accessing the stored data. Alternatively, if a data quality flag **118** is set to a value that indicates a positive data quality, access to an associated datastore **114** may be enabled. The data quality flag(s) **118** may also prevent or enable access to the datastore(s) **114** by data producers, and may control whether data producers are permitted to write or update data in the datastore(s) **114**. By setting the data quality flag(s) **118**, the data quality server device(s) **104** may control access to the datastore(s) **114** based on the determined data quality of the datastore(s) **114**.

In addition to setting values of the data quality flag(s) **118**, the rule application module **110** may perform other actions based on the results of applying the data quality rules **108**. In some implementations, the rule application module **110** may send one or more issue notifications **124** to inform one or more users of the results of applying the data quality rules **108**. The issue notification(s) **124** may indicate a positive data quality or a negative data quality for the datastore(s) **114**. Implementations support issue notification(s) **124** sent through any mode of communication, including, but not limited to, emails, text messages, voice messages, faxes, instant messages, or issue tickets entered into an issue tracking or bug tracking system.

In some cases, an issue notification **124** describing the result(s) of applying a particular data quality rule **108** may be sent to one or more individuals identified as owners of, or authors of, the data quality rule **108**. Such individuals may be data consumers, data producers, or others, and the issue notification(s) **124** may be sent to the user device(s) **102** associated with such individuals. Further, one or more issue notification(s) **124** may be sent to subscribers **126**. The subscribers **126** may include users, groups of users, processes, devices, e-mail lists, or other entities who have subscribed to receive notifications regarding the results of applying one or more data quality rules **108**. The subscriber(s) **126** may also include owners or authors of the data quality rule(s) **108**. In some implementations, the rule application module **110** may create or update one or more log files to store information regarding the execution of the data quality rule(s) **108**, the log file(s) being accessible by a system administrator or other user(s).

In some implementations, the various devices of the environment **100** may communicate with one another using one or more networks. Such networks may include public networks such as the Internet, private networks such as an institutional or personal intranet, or some combination of private and public networks. The networks may include any type of wired or wireless network, including but not limited to local area networks (LANs), wide area networks (WANs), wireless WANs (WWANs), wireless LANs (WLANs), and mobile communications networks (e.g. **3**G, **4**G, and so forth).

FIG. **2** depicts a block diagram **200**, depicting an example system architecture for the data quality server device(s) **104** shown in FIG. **1**. As shown in block diagram **200**, the data quality server device(s) **104** may include one or more processors **202** configured to execute one or more stored instructions. The processor(s) **202** may comprise one or more cores.

The data quality server device(s) **104** may include one or more input/output (I/O) devices **204**. The I/O device(s) **204** may include user input devices such as a keyboard, a mouse, a pen, a game controller, a voice input device, a touch input device, a gestural input device, a haptic input device, or other devices. The I/O device(s) **204** may also include output devices such as a display, a printer, audio speakers, haptic output devices, and so forth. The I/O device(s) **204** may be physically incorporated with the data quality server device(s) **104**, or may be externally placed.

The data quality server device(s) **104** may include one or more I/O interfaces **206** to enable components or modules of the data quality server device(s) **104** to control, interface with, or otherwise communicate with the I/O device(s) **204**. The I/O interface(s) **206** may enable information to be transferred in to the data quality server device(s) **104**, out of the data quality server device(s) **104**, or between components of the data quality server device(s) **104**. Information may be transferred through serial communication, parallel communication, or other types of communication. For example, the I/O interface(s) **206** may comply with the RS-232 standard for serial ports, or with the Institute of Electrical and Electronics Engineers (IEEE) 1284 standard for parallel ports. As another example, the I/O interface(s) **206** may be configured to provide a Universal Serial Bus (USB) connection. The data quality server device(s) **104** may also include one or more busses or other internal communications hardware or software that allow for the transfer of data between the various modules and components of the data quality server device(s) **104**.

The data quality server device(s) **104** may include one or more network interfaces **208** to enable communications between the data quality server device(s) **104** and other networked devices, such as the user device(s) **102** or the data storage system(s) **112**. The network interface(s) **208** may include one or more network interface controllers (NICs) or other types of transceiver devices configured to send and receive communications over a network.

The data quality server device(s) **104** may include one or more memories, described herein as memory **210**. The memory **210** comprises one or more computer-readable storage media (CRSM). The CRSM may be any one or more of an electronic storage medium, a magnetic storage medium, an optical storage medium, a quantum storage medium, a mechanical computer storage medium, and so forth. The memory **210** provides storage of computer-readable instructions, data structures, program modules, and other data for the operation of the data quality server device(s) **104**.

The memory **210** may include an operating system (OS) module **212**. The OS module **212** is configured to manage hardware resources such as the I/O device(s) **204**, the I/O interface(s) **206**, and the network interface(s) **208**, and to provide various services to applications, processes, or modules executing on the processor(s) **202**. The OS module **212** may include one or more of the following: any version of the Linux® operating system originally released by Linus Torvalds; any version of iOS® from Apple Corp. of Cupertino, Calif.; any version of Windows® or Windows Mobile® from Microsoft Corp. of Redmond, Wash.; any version of Android® from Google, Corp. of Mountain View, Calif. and its derivatives from various sources; any version of Palm OS® from Palm Computing, Inc. of Sunnyvale, Calif. and its derivatives from various sources; any version of BlackBerry OS® from Research In Motion Ltd. of Waterloo, Ontario, Canada; any version of VxWorks® from Wind River Systems of Alameda, Calif.; or other operating systems.

In some implementations, the memory **210** includes the rule management interface module **106**. The rule management interface module **106** may provide one or more user interfaces accessible to the user device(s) **102**, enabling data consumers, data producers, or other users to provide the data quality rule(s) **108** or other information. In cases where the user interface(s) are provided through one or more web pages, the rule management interface module **106** may include a web server such as the Apache Web Server®, from the Apache Software Foundation, Internet Information Services® (IIS), from the Microsoft Corporation of Redmond, Wash., or another web server.

The memory **210** may also include the rule application module **110**. The rule application module **110** may perform operations to apply the data quality rule(s) **108** to determine data quality of the data stored in the datastore(s) **114**. The rule application module **110** may also perform one or more actions based on the determined data quality, such as set the data quality flag(s) **118** based on the results of applying the data quality rule(s) **108**, and send the issue notification(s) **124** to inform users of the results. In some implementations, the rule application module **110** includes an issue notification module **214** to generate and send the issue notification(s) **124**. The rule application module **110** may also include a statistics processing module **216** to perform one or more mathematical or statistical operations to determine whether the data quality rule(s) **108** are satisfied, to generate a sample data set for rules application, or for other purposes. Operations of the rule application module **110** are described further with reference to FIGS. **4-10**.

The memory **210** may also include one or more other modules **218**, such as a user authentication module, an access control module, a security or cryptography module, and so forth.

The memory **210** may also include a data quality datastore **220** to store information for operations of the data quality server device(s) **104**. The data quality datastore **220** may comprise a database, array, structured list, tree, or other data structure, and may be a relational or a non-relational datastore. The data quality datastore **220** may store one or more of the data quality rule(s) **108**, the issue notification(s) **124**, and the data quality flag(s) **118**. The data quality datastore **220** may also store other data **222**, such as user account information, user authentication information, and so forth. In some implementations, at least a portion of the information stored in the data quality datastore **220** may be stored externally to the data quality server device(s) **104**, on other devices that are accessible to the data quality server device(s) **104** via the I/O interface(s) **206** or the network interface(s) **208**.

FIG. **3** depicts a schematic **300** of an example data structure for the data quality rule(s) **108**. The data quality rule(s) **108** may be expressed in any type of data structure, or in unstructured data. In some implementations, the data quality rule(s) **108** are expressed in a markup language such as XML. Implementations may employ any number of data quality rules **108** to determine data quality.

In some implementations, each of the data quality rule(s) **108** includes a rule identifier **302**. The rule identifier **302** may include textual data, numeric data, or other data that identifies the data quality rule **108**. In some cases, the rule identifier **302** may uniquely identify the data quality rule **108**. The rule identifier **302** may also include a textual description of the data quality rule **108** in a human-readable format. For example, the rule identifier **302** may describe the condition(s) for the data quality rule **108**, the datastore to which the data quality rule **108** is to be applied, the times when the data quality rule **108** is to be applied, and so forth.

The data quality rule **108** may also include an identification of data for rule application **304**. The identification **304** may include an identifier for one or more datastores **114** for which data quality is to be determined. The identification **304** may also include one or more segments, subsets, tables, data attributes, or other portions of the one or more datastores **114** for which data quality is to be determined. For example, the identification **304** may indicate that data quality is to be determined for data stored in TableX, TableY, and TableZ of datastore A. As another example, the identification **304** may indicate that data quality is to be determined for the data that was stored in datastore B during a particular range of dates or times.

The data quality rule **108** may include an identification **306** that identifies one or more rule owners. The identification **306** may include a username, email address, alias, given name, identification number, telephone number, or other identifying information for one or more data consumers, data producers, or other users who are owners of the data quality rule **108**. The owners may include one or more users who authored, defined, or created the data quality rule **108**, and who may receive an issue notification **124** describing the results of applying the data quality rule **108**.

In some cases, the data quality rule **108** may also include an identification **308** that identifies the one or more subscribers **126**. The subscribers **126** may include one or more users, processes, devices, or other entities who have an interest in the results of the application of data quality rule **108** even though they may not have authored, defined, or created the data quality rule **108**. Such users may also receive an issue notification **124** describing the results of applying the data quality rule **108**. The user(s) identified in one or both of the identification **306** and the identification **308** may receive notice of a positive or negative data quality determination for data in one or more datastores **114**.

Some implementations provide for the generation of a sample data set that is at least a portion of the data stored in a datastore **114**. The data quality rule(s) **108** may be applied to the sample data set to determine a data quality of data stored in the datastore **114**. The data quality rule **108** may include one or more sampling parameters **310**, indicating a sample amount of data to include in the sample data set.

In some cases, the sampling parameter(s) **310** may indicate a relative amount of data for rule application, such as a proportion or percentage of the data identified in identification **304**. For example, the sampling parameter(s) **310** may indicate that 1%, 5%, 10%, or another percentage of the stored data is to be retrieved to generate a sample data set. Alternatively, the sampling parameter(s) **310** may indicate an absolute amount of data (e.g., 1 gigabyte) to include in the sample data set. In some cases, the sampling parameter(s) **310** may indicate a sample amount based on a time period. For example, the sampling parameter(s) **310** may indicate that the sample data set is to include a portion of the stored data that was written to storage on a particular day, during a particular week, or during some other time period. In some cases, the sample data set may include substantially all of the data stored in a datastore **114**.

The data quality rule **108** may include one or more mathematical conditions **312**. Each of the mathematical condition(s) **312** may indicate a condition to be met for the data quality rule **108** to be satisfied. In some cases, a data quality rule **108** is satisfied if all the mathematical condition(s) **312** are satisfied. Alternatively, a data quality rule **108** may be satisfied if one or more mathematical conditions **312** are satisfied. Implementations support various types of the mathematical condition(s) **312**, and each mathematical condition **312** may test or evaluate the sample data set. In some implementations, a mathematical condition **312** is satisfied if it evaluates to true.

The mathematical condition(s) **312** may include a condition to check whether a current size of the sample data set is within a predetermined margin of a historical average size of the sample data set. For example, if a current size of the sample data set is not within 10% of the historical average size of the sample data set, the condition may not be met and the data quality rule **108** may not be satisfied. Mathematically, this condition may be expressed as in Formula 1 below.

$$-0.1<(S_{current}-S_{average})/S_{average}<0.1 \qquad \text{(Formula 1)}$$

In Formula 1, $S_{current}$ corresponds to a current size of the sample data set, and $S_{average}$ corresponds to a historical average size of the sample data set.

As used herein, an average value may refer to any mathematical formulation that provides a statistical measure of a central tendency for a distribution. Accordingly, an average may include an arithmetic mean, a median, a mode, and so forth. In some cases, the mathematical condition(s) **312** may also include a condition to check whether a current size of the sample data set is within a predetermined margin of a value that is halfway between a maximum and a minimum historical size of the sample data set. For example, if a current size of the sample data set is not within 5% of such a value halfway between maximum and minimum, the condition may not be met. Mathematically, this condition may be expressed as in Formula 2 below.

$$0.95-(S_{max}+S_{min})/2\times S_{current}<1.05 \qquad \text{(Formula 2)}$$

In Formula 2, $S_{current}$ corresponds to a current size of the sample data set, S_{max} corresponds to a historical maximum size of the sample data set, and S_{min} corresponds to a historical minimum size of the sample data set. The maximum and minimum may be determined based on analysis of a particular time period worth of data (e.g., a month or year worth of data). The mathematical condition(s) **312** may also include conditions on other statistical measures for the size of the sample data set, including but not limited to, its maximum, minimum, range, or standard deviation. Moreover, implementations may employ various statistical models or algorithms to evaluate whether the mathematical conditions(s) **312** are satisfied, including, but not limited to, confidence intervals, correlation analyses, analysis of variance (ANOVA) techniques, regression analyses, and so forth.

The mathematical condition(s) **312** may include a condition to check whether a change in the size of the sample data set is within a predetermined margin of a historical variation in the size of the sample data set. For example, if the size of the sample data set has varied over a period of time (e.g., a day), and the amount of the variation (e.g., the delta) is more than 10% of a historical average variation of the sample data set, the condition may not be met. Mathematically, such a condition may be expressed as in Formula 3 below.

$$-0.1<(\Delta S_{current}-\Delta S_{average})/\Delta S_{average}<0.1 \qquad \text{(Formula 3)}$$

In Formula 3, $\Delta S_{current}$ corresponds to a current variation in the size of the sample data set over a period of time (e.g., a day), and $\Delta S_{average}$ corresponds to a historical average change in the size of the sample data set over similar periods of time.

As used herein, a data attribute may correspond to a column in a table (e.g., in a relational datastore) or may correspond to a searchable data element in a non-relational datastore. In some implementations, the mathematical condition(s) **312** may include a condition to check whether a current count of rows or records for which a particular data attribute stores a particular value is within a predetermined margin of a historical average count of such rows or records. For example, if a current count of rows or records for which a data attribute “Sale Price” stores a particular value 0.00 is outside a predetermined margin (e.g., 5%) of a historical average count of such rows or records, the condition may not be met. Mathematically, this condition may be expressed as in Formula 4 below.

$$-0.05<(C_{current}-C_{average})/C_{average}<0.05 \qquad \text{(Formula 4)}$$

In Formula 4, $C_{current}$ corresponds to a current count of rows or records for which a data attribute stores a particular value in the sample data set, and $C_{average}$ corresponds to a historical average count of such rows or records.

The above examples of mathematical condition(s) **312** are not limiting or exhaustive, and implementations may support other types of mathematical condition(s) **312**. Although the examples herein describe mathematical conditions **312** to test a sample data set that is a portion of the data stored in a datastore **114**, implementations also support the application of the mathematical condition(s) **312** to a data set that includes substantially all of the data stored in a datastore **114**. Moreover, Formulae 1-4 provide examples of the described mathematic condition(s) **312**, and implementations may support calculations or algorithms other than these examples.

Moreover, the historical average size or historical average count described above may be evaluated based on previous measurements of the size or count over any period of time, such as a previous week, a previous month, and so forth. In some cases, the time period may be based on a particular event, holiday, season, and so forth. For example, a particular sample data set may include clickstream data for an e-commerce web site, and the amount of stored clickstream data may be expected to increase over a busy shopping season. In such cases, the time period for comparison may be a previous shopping season. Alternatively, the mathematical condition(s) **312** may incorporate one or more adjustments to account for the expected increase in the amount of stored data. By comparing a current size or current count against historical data, implementations may operate to identify deviations of a current state of the datastore **114** from a normative state, and infer potential problems based on the identified deviations.

In some implementations, the data quality rule **108** may include a description of one or more actions **314** to perform if the data quality rule **108** is not satisfied. Such action(s) **314** may include setting a data quality flag **118** to limit or suspend access to the corresponding datastore **114**. The action(s) **314** may also include sending one or more issue notifications **124** to data consumers, data producers, or other users. The issue notification(s) **124** may be sent via any mode of communication and in any format, including, but not limited to, emails, text messages, voice messages, faxes, and so forth. In some cases, the issue notification(s) **124** may include generating an issue ticket or bug report to be automatically entered into an issue tracking or bug tracking system. The issue notification(s) **124** may also be communicated through a user interface provided by the rule management interface module **106**.

The issue notification(s) **124** may include a description of the data quality rule **108** that was not satisfied (e.g., that failed), a description or identification of the datastore(s) **114** to which the data quality rule **108** was applied, a description of the sample data set to which the data quality rule was applied (e.g., the sample amount of data, which tables, rows, or data attributes were tested, and so forth), the identification of the rule owner(s) **306**, a time when the data quality rule **108** was applied, and so forth.

The data quality rule **108** may include one or more timing parameter(s) **316** indicating one or more start times when the data quality rule **108** is to be applied. For example, a data quality rule **108** may be scheduled to be applied periodically, such as daily, weekly, or monthly, at a particular time of day, on a particular day of the week, or on a particular day of the month, and so forth. As another example, the data quality rule **108** may be scheduled to be applied one or more times on particular dates and at particular times.

In some cases, the timing parameter(s) **316** may be specified to accommodate expected variations over a period of time. For example, a particular dataset may vary in size or vary in the amount of data added over a period of time such as a day, and such variations may exhibit an expected pattern (e.g., more data added during the day, and less data added during the night, and so forth). In such cases, the timing parameter(s) **316** may indicate that the data quality rule **108** is to be executed with a periodicity such that the expected variations do not lead to an inference of low data quality.

FIG. **4** depicts a schematic **400** showing the enabling and disabling of access to a plurality of datastores **114** through the use of one or more data quality flags **118** that each indicate a data quality of a datastore **114**, in a scenario where there is a linear data flow between at least some of the datastores **114**.

In the scenario illustrated in FIG. **4**, a first data set from a first datastore **114(1)** may be read by a first data consuming entity **122(1)**, which employs the first data set to generate a second data set that may be written to a second datastore **114(2)**. A second data consuming entity **122(2)** may read the second data set from the second datastore **114(2)**, and generate a third data set which is written to a third datastore **114(3)**.

The third data set may then be read by a third data consuming entity **122(3)**, and so forth. In this way, one or more of the data consuming entities **122** may also be a data producing entity. Each entity may read data from the datastore(s) **114** and may re-write that data, or write newly generated data, to the datastore(s) **114**. The top diagram of FIG. **4** depicts a first system state **402**, in which data access is enabled for the one or more datastores **114**.

Because downstream data consumers and producers may be reading, writing, and generally using data that is derived from or in some way dependent on upstream data, low data quality of the upstream data may cause a cascade of data quality issues or system problems for the downstream data consumers and producers. The bottom diagram of FIG. **4** depicts a second system state **404**, in which data access has been disabled for at least one of the datastores **114**. In some implementations, access to data stored on a datastore **114** may be permitted, suspended, or limited based on the value stored in the corresponding data quality flag **118**. In this example, a negative data quality has been determined for the datastore **114(2)**, and a corresponding data quality flag **118(2)** has been set to a value indicating the negative data quality. In this example, write operations are enabled to write data to the datastore **114(2)** by the data consuming entity **122(1)**, but the data consuming entity **122(2)** is blocked from reading data stored in the datastore **114(2)**. In some implementations, writes or updates to data stored in a datastore **114** may also be suspended based on a value of the corresponding data quality flag **118**.

Implementations support various techniques by which data access is suspended or blocked based on the value of a data quality flag **118**. In some cases, the data consuming entities **122** may check a value of the data quality flag **118** before attempting to access data stored on a corresponding datastore **114**, and may determine to not access the data if the data quality flag **118** indicates a negative data quality. Alternatively, a database management system or another software component associated with the datastore **114** may check a value of the data quality flag **118** in response to receiving an access request from a data consuming entity **122**, and may block such access if the data quality flag **118** indicates a negative data quality.

In some cases, access to all of the data stored on a datastore **114** may be suspended or blocked if a corresponding data quality flag **118** indicates a negative data quality. Alternatively, access to a portion of the stored data may be suspended. For example, access to data associated with a particular region (e.g., North America, Europe, Asia, and so forth) may be suspended, but access to other data may be permitted. As another example, access to data associated with a particular table, data attribute, or time period, or access to rows or records that store particular data (e.g., data associated with a particular merchant or product) may be suspended, but access to other data may be permitted. In this way, implementations may control data access with any degree of granularity or specificity.

FIG. **5** depicts a schematic **500** showing the enabling and disabling of access to a datastore **114(1)** through the use of a data quality flag **118(1)** that indicates a data quality of the datastore **114(1)**. FIG. **5** illustrates a scenario in which there is a cyclic data flow to and from a datastore **114(1)**. In this scenario, a particular data consuming entity **122** may read data from the datastore **114(1)**. The data consuming entity **122** may then write at least a portion of that data, or write newly generated data, to the same datastore **114(1)**.

The top diagram of FIG. **5** depicts a first system state **502**, in which data access is enabled for the datastore **114(1)**. The bottom diagram of FIG. **5** depicts a second system state **504** in which data access to the datastore **114**(**1**) has been disabled through the setting of the associated data quality flag **118**(**1**), based on a determination of a negative data quality for the datastore **114**(**1**). In this case, both reads and writes to the datastore **114**(**1**) have been suspended. Such a suspension may prevent further data corruption or system problems that may occur if the data consuming entity **122**(**1**) were allowed to continue accessing the low quality data, and allowed to generate and write new data based on the low quality data.

In some cases, the data quality flag(s) **118** may be preemptively set to a particular value based on detected or scheduled outages in one or more data producing entities. For example, if it is detected that a particular server is experiencing downtime, and that particular server is a data producing entity that stores data in a datastore **114**, then a corresponding data quality flag **118** may be set to suspend access to the datastore **114** during the downtime. In such cases, suspending access to the datastore **114** may prevent data consuming entities **122** from reading corrupt or incomplete data from the datastore **114**. In some cases, data producing servers or other devices may be periodically polled by the data quality server device(s) **104** to determine their status or activity. If such devices are nonresponsive to the polling, access may be suspended to one or more datastore(s) **114** that may store data that would otherwise be produced by the inactive devices.

FIG. **6** depicts a flow diagram **600** of a process for applying one or more data quality rules **108** to data stored in one or more datastores **114**, and performing one or more actions **314** based on the results of the application of the data quality rule(s) **108**. Operations included in the process may be performed on one or more of the user device(s) **102**, the data quality server device(s) **104**, or the data storage system(s) **112**. Operations performed on the data quality server device(s) **104** may be performed by the rule management interface module **106**, the rule application module **110**, or other modules.

At **602**, the process may access one or more data quality rules **108** stored in memory. In some implementations, the data quality rule(s) **108** may be stored in memory **210** on the data quality server device(s) **104**. Alternatively, at least a portion of the data quality rule(s) **108** may be stored externally to the data quality server device(s) **104**.

At **604**, a determination is made to identify at least one of the data quality rule(s) **108** to apply to data stored in one or more datastore(s) **114**. In some implementations, one or more default data quality rule(s) **108** may be selected. The determination may also be based on information included in the data quality rule(s) **108**. For example, in cases where data quality is to be tested for a particular datastore **114**, those data quality rule(s) **108** may be selected for which the identification **304** identifies the datastore **114**.

At **606**, the determined data quality rule(s) **108** are applied to data stored in the datastore(s) **114**, to determine the data quality of the datastore(s) **114**. Application of the data quality rule(s) **108** is described further with reference to FIG. **7**. In some cases, the data quality rule(s) **108** may be applied to a sample data set that includes a portion of the data stored in the datastore(s) **114**. Determination of the sample data set is described further with reference to FIG. **8**.

At **608**, a determination is made whether the data quality rule(s) **108** are satisfied. If not, then at **610** one or more actions **314** may be performed based on a negative data quality determination for the datastore(s) **114**. If the determination at **608** is positive, then at **612** one or more actions **314** may be performed based on a positive data quality determination for the datastore(s) **114**. The action(s) **314** are described further with reference to FIGS. **9** and **10**.

FIG. **7** depicts a flow diagram **700** of a process for applying one or more data quality rules **108** to data stored in the datastore(s) **114**. This process may include generating a sample data set and applying one or more mathematical conditions **312** to the sample data set to determine whether the data quality rule(s) **108** are satisfied. Operations included in the process may be performed on one or more of the user device(s) **102**, the data quality server device(s) **104**, or the data storage system(s) **112**. Operations performed on the data quality server device(s) **104** may be performed by the rule management interface module **106**, the rule application module **110**, or other modules.

At **702**, a sample data set is generated by retrieving or identifying at least a sample amount of data stored in the datastore(s) **114** to be tested. In some implementations, the sample data set may be identified and retrieved from the datastore(s) **114** through a get operation or other type of data retrieval operation. Alternatively, the sample data set may be identified as a portion of the stored data and analyzed in place through one or more read or scan operations. In some cases, the sample amount may be based on the sampling parameter(s) **310** included in the data quality rule(s) **108** to be applied, as described above. Determination of the sampling data set is described further with reference to FIG. **8**.

In some implementations, applying a data quality rule **108** may include applying the one or more mathematical condition(s) **312** described in the data quality rule **108**. At **704**, one or more mathematical conditions **312** may be identified, the mathematical condition(s) **312** being included in the data quality rule **108**. At **706**, the mathematical condition(s) **312** may be applied to the sample data set, as described above with reference to FIG. **3**.

At **708**, a determination is made whether the mathematical condition(s) **312** are satisfied for the sample data set. If not, then at **710** a determination may be made that the data quality rule(s) **108** are not satisfied for the datastore(s) **114**. If so, then at **712** a determination may be made that the data quality rule(s) are satisfied for the datastore(s) **114**. One or more actions **314** may then be performed based on the determination at **710** or **712**, as described further with reference to FIGS. **9** and **10**. In some implementations, a data quality rule **108** is satisfied if all of its mathematical condition(s) **312** are satisfied. Alternatively, a data quality rule **108** may be satisfied if at least some of its mathematical condition(s) **312** are satisfied.

FIG. **8** depicts a flow diagram **800** of a process for determining a sample set of data for applying the data quality rule(s) **108**. Operations included in the process may be performed on one or more of the user device(s) **102**, the data quality server device(s) **104**, or the data storage system(s) **112**. Operations performed on the data quality server device(s) **104** may be performed by the rule management interface module **106**, the rule application module **110**, or other modules.

At **802**, a determination is made whether one or more sampling parameters **310** are included in the data quality rule(s) **108** to be applied. If so, then at **804** a sample amount of data to be included in the sample data set is determined based on the sampling parameter(s) **310**. As described above, the sampling parameter(s) **310** may indicate a relative amount of data to include in the sample data set, such as a proportion or percentage of the data stored in the datastore **114**. Alternatively, the sampling parameter(s) **310** may indicate a particular, absolute amount of data (e.g., 1 gigabyte) to include in the sample data set. In some cases, the sampling parameter(s) **310** may indicate a sample amount based on a time period, such as an amount of data written to the datastore **114** during a particular day, week, month, and so forth.

If the determination at **802** is negative, then at **806** a determination is made whether there is an indication of a time period during which the application of the data quality rule(s) **108** is to be substantially completed. Such an indication may have been provided by a user, and may be included in the timing parameter(s) **316** of the data quality rule(s) **108**. If so, then at **808** the sample amount of data to include in the sample data set may be dynamically determined based on the time period, such that applying the data quality rule(s) **108** is substantially completed within the time period. For example, a time period of ten minutes may be specified by a user, indicating that the application of a data quality rule **108** is to be substantially completed within ten minutes. A determination may be made that the data quality rule **108** may substantially complete within ten minutes if it is applied to a sample data set that is 0.001% of a 10 peta byte datastore (e.g., 10 gigabytes). In this way, implementations may enable a performance-based tuning of the application of the data quality rules **108**.

If the determination at **806** is negative, then at **810** a default sample amount may be employed, either as a relative amount of data or an absolute quantity of data as described above. In some cases, the default sample amount may be determined based on an amount that is statistically significant as compared to a total quantity of data stored in the datastore(s) **114**. Such a determination may reflect a statistical assessment as to whether the results of the application of the data quality rule(s) **108** would be substantially accurate in their determination of data quality, or whether the results may be dictated by chance. A sample amount for the sample data set may be determined to minimize the possibility of a chance-based outcome.

At **812**, the sample data set is generated by retrieving the sample amount of data from the datastore(s) **114** for which data quality is to be determined. In some cases, the sample amount of data may be a random sample of the data stored in the datastore(s) **114**. At **814**, the data quality rule(s) **108** may be applied to the sample amount of data, as described further herein.

FIG. **9** depicts a flow diagram **900** of a process for performing one or more actions **314** based on the results of applying the data quality rule(s) **108**. Operations included in the process may be performed on one or more of the user device(s) **102**, the data quality server device(s) **104**, or the data storage system(s) **112**. Operations performed on the data quality server device(s) **104** may be performed by the rule management interface module **106**, the rule application module **110**, or other modules.

At **902**, one or more data quality rules **108** are applied to a sample data set, to determine the data quality of data stored in one or more datastores **114** as described above. At **904**, a determination is made whether the data quality rule(s) **108** are satisfied.

If the determination at **904** is negative, then a negative data quality may be inferred for the data stored in the datastore(s) **114**, and one or more actions **314** may be performed based on that inference. Such actions **314** may include one or more of the actions described in operations **906**, **908**, **910**, and **912**.

At **906**, one or more data quality flag(s) **118**, or other indicia of data quality, may be set to a value that indicates a negative data quality for the datastore(s) **114**, as described above. At **908**, access to the datastore(s) **114** may be at least partly suspended based on the data quality flag(s) **118** indicating a negative data quality for the datastore(s) **114**. This suspension may proceed as described above with reference to FIGS. **3** and **4**.

At **910**, in some implementations one or more additional data quality rules **108** may be applied based on the negative data quality determination. In some cases, multiple data quality rules **108** may be associated or linked to one another, such that the failure of one rule leads to the application of a related rule. Such rule associations may be described in the data quality rules **108**. Alternatively, the data quality rule(s) **108** may be reapplied to test a different sample data set. This implementation is described further with reference to FIG. **10**. In some implementations, the output or result of applying one or more data quality rules **108** may be employed as an input to the same or a different set of one or more data quality rules **108**.

At **912**, one or more issue notification(s) **124** may be sent to inform one or more users, processes, or devices that a negative data quality has been determined for the datastore(s) **114**. The issue notification(s) **124** may be sent by any medium and in any format, such as emails, text messages, voice messages, faxes, issue tickets added to an issue tracking system, information provided through the rule management interface module **106**, and so forth. The issue notification(s) **124** may be sent to the rule owner(s) identified by identification **306**, to the rule subscriber(s) **126** identified by identification **308**, to both the rule owner(s) and the rule subscriber(s) **126**. In some cases, the issue notification(s) **124** may be sent to other users, such as system administrators and so forth.

As described above, the issue notification(s) **124** may include information to enable a recipient to investigate or diagnose a cause of the negative data quality, or identify a solution to correct the negative data quality. Accordingly, the issue notification(s) **124** may include a description or identification of the datastore(s) **114** to which the data quality rule(s) **108** were applied, the sample data set tested, the data quality rule(s) **108** applied, a date and time when the data quality rule(s) **108** were applied, and so forth.

The action(s) **314** may include one or more of the actions described in operations **906**, **908**, **910**, and **912**, performed in any order, and implementations are not limited to performing all such operations. For example, in some implementations an issue notification **124** may be sent following a determination of negative data quality for a datastore **114**, even though access to the datastore **114** is not suspended.

If the determination at **904** is positive, then a positive data quality may be inferred for the data stored in the datastore(s) **114**, and one or more actions **314** may be performed based on that inference. Such actions **314** may include one or more of the actions described in operations **914**, **916**, **918**, and **920**, which may be performed in any order. Implementations are not limited to performing all such operations.

At **914**, one or more data quality flag(s) **118**, or other indicia of data quality, may be set to a value that indicates a positive data quality for the datastore(s) **114**, as described above. At **916**, access to the datastore(s) **114** may be at least partly enabled based on the data quality flag(s) **118** indicating a positive data quality for the datastore(s) **114**. This enabling of access may proceed as described above with reference to FIGS. **3** and **4**.

Implementations support either or both of a default positive or default negative configuration for controlling access to the datastore(s) **114**. For example, in some implementations a data quality flag **118** may indicate a negative data quality for a corresponding datastore **114** as a default, until the stored data is tested and a positive data quality is determined. Following the determination of the positive data quality, the data quality flag **118** may be set to a value indicating a positive data quality, and access to the datastore **114** may be enabled. Alternatively, in some implementations the data quality flag **118** may indicate a positive data quality for the datastore **114** as a default, until the stored data is tested and a negative data quality is determined. Following the determination of the negative data quality, the data quality flag **118** may be set to a value indicating a negative data quality, and access to the datastore **114** may be at least partly suspended.

At **918**, in some implementations one or more additional data quality rules **108** may be applied based on the positive data quality determination. In some cases, multiple data quality rules **108** may be associated or linked to one another, such that the positive result of one rule leads to the application of a related rule. Such rule associations may be described in the data quality rules **108**. Alternatively, the data quality rule(s) **108** may be reapplied to test a different sample data set. In some implementations, the output or result of applying one or more data quality rules **108** may be employed as an input to the same or a different set of one or more data quality rules **108**.

At **920**, one or more issue notification(s) **124** may be sent to inform one or more users, processes, devices, or other entities that a positive data quality has been determined for the datastore(s) **114**. The issue notification(s) **124** may be sent to rule owner(s), rule subscriber(s), or other users as described above. In some implementations, the issue notification(s) **124** may be sent based on a determination of negative data quality and may not be sent based on a determination of positive data quality. Alternatively, the issue notification(s) **124** may be sent based on a determination of positive data quality and may not be sent based on a determination of negative data quality. In some implementations, the issue notification(s) **124** may be sent based on a determination of positive or negative data quality.

FIG. **10** depicts a flow diagram **1000** of a process for iteratively applying the data quality rule(s) **108** to sample data sets of varying size, based on the results of previous applications of the data quality rule(s) **108**. Operations included in the process may be performed on one or more of the user device(s) **102**, the data quality server device(s) **104**, or the data storage system(s) **112**. Operations performed on the data quality server device(s) **104** may be performed by the rule management interface module **106**, the rule application module **110**, or other modules.

At **1002**, one or more data quality rules **108** may be applied to a sample data set retrieved from one or more datastore(s) **114**, as described above. At **1004**, a determination is made whether the data quality rule(s) **108** are satisfied. If so, at **1006** one or more actions **314** may be performed based on a positive data quality determination as described above.

If the determination at **1004** is negative, at **1008** a determination may be made whether to re-apply the data quality rule(s) **108** to a different sample data set retrieved from the datastore(s) **114**. If the determination at **1008** is negative, at **1010** one or more actions **314** may be performed based on a negative data quality determination as described above.

If the determination at **1008** is positive, then the sample amount may be changed to generate a different sample data set for determining the data quality of the datastore(s) **114**. In some implementations, the sample amount may be increased at **1012** to provide for a larger sample data set. The process may then return to **1002**, and re-apply the data quality rule(s) **108** to the larger sample data set.

In this way, the process may iterate until a positive data quality determination is made at **1004**, or until a determination is made at **1008** to stop iterating. Some implementations may support a maximum number of iterations, which may be tuned automatically or manually based on system performance. Some implementations may perform such iterations until the sample data set reaches a certain threshold (e.g., maximum) size. This threshold size may also be tuned automatically or manually based on system performance.

Some implementations may employ supervised or unsupervised machine learning techniques to tune existing data quality rules **108**, or generate new data quality rules **108**, based on the results of previous applications of data quality rules **108**. Such machine learning techniques may analyze a current set of data quality rule(s) **108** and identify one or more elements (e.g., mathematical conditions, and so forth) that are shared by different rules. Based on the identified common elements, one or more new data quality rules **108** may be extrapolated and applied to determine data quality.

Moreover, in some cases, data stored in the datastore(s) **114** may be analyzed and data quality rule(s) **108** may be extrapolated based on that data. For example, in a particular datastore **114** one or more data attributes may be identified as suitable targets for data quality determination using one or more new data quality rules **108**. Machine learning techniques may then be employed to automatically determine one or more mathematical conditions **312**, one or more sampling parameters **310**, and other elements of the new data quality rules(s) **108** based on the data stored in the identified data attribute(s).

Those having ordinary skill in the art will readily recognize that certain steps or operations illustrated in the figures above can be eliminated, combined, subdivided, executed in parallel, or taken in an alternate order. Moreover, the methods described above may be implemented as one or more software programs for a computer system and are encoded in one or more computer-readable storage media as instructions executable on one or more processors.

Separate instances of these programs may be executed on or distributed across separate computer systems. Thus, although certain steps have been described as being performed by certain devices, software programs, processes, or entities, this need not be the case and a variety of alternative implementations will be understood by those having ordinary skill in the art.

Additionally, those having ordinary skill in the art readily recognize that the techniques described above can be utilized in a variety of devices, environments, and situations. Although the present disclosure is written with respect to specific embodiments and implementations, various changes and modifications may be suggested to one skilled in the art and it is intended that the present disclosure encompass such changes and modifications that fall within the scope of the appended claims.

What is claimed is:

1. A system, comprising:

at least one memory storing computer-executable instructions; and

at least one processor in communication with the at least one memory, the at least one processor configured to access the at least one memory and execute the computer-executable instructions to:

access at least one data quality rule stored in the at least one memory, the at least one data quality rule applying one or more statistical measures of data quality of data stored in at least one datastore, the at least one data quality rule including:

an identification of at least a portion of the data stored in the at least one datastore;

a sampling parameter indicating a sample amount of the at least a portion of the data to include in a sample data set, wherein the sample amount includes one or more of a proportion or percentage of the at least a portion of the data;

at least one mathematical condition applicable to the sample data set, wherein the at least one mathematical condition includes at least one condition that a current size of the sample data set is within a predetermined margin of a historical average size of the sample data set; and

an identification of at least one subscriber associated with the at least one data quality rule;

generate the sample data set by identifying the sample amount of the at least a portion of the data in the at least one datastore;

determine whether the at least one mathematical condition is satisfied for the sample data set;

based on determining that the at least one mathematical condition is not satisfied, suspend access to the at least one datastore by setting at least one data quality flag in the at least one memory to a value indicating a negative data quality for at least a portion of the data stored in the at least one datastore; and

send at least one notification to the at least one subscriber, the at least one notification indicating that the at least one data quality rule is not satisfied for the at least one datastore.

2. The system of claim **1**, wherein the at least one datastore includes at least one relational datastore and at least one non-relational datastore.

3. The system of claim **1**, wherein the at least one mathematical condition includes at least one condition that a current count of records for which a data attribute stores a particular value is within a predetermined margin of a historical average count of records for which the data attribute stores the particular value, the records being included in the sample data set.

4. A computer-implemented method, comprising:

accessing at least one data quality rule stored in at least one memory, the at least one data quality rule being applicable to determine at least one statistical measure of data quality of data stored in at least one datastore, the at least one data quality rule including:

a sampling parameter that indicates a sample amount of the data to include in a sample data set; and

at least one mathematical condition applicable to the sample data set;

applying the at least one data quality rule to the data stored in the at least one datastore, including:

generating the sample data set by identifying the sample amount of the data in the at least one datastore; and

determining whether the at least one mathematical condition is satisfied for the sample data set, wherein the at least one mathematical condition includes at least one condition that a current size of the sample data set is within a predetermined margin of a historical size of the sample data set; and

based on determining that the at least one mathematical condition is not satisfied, setting at least one data quality flag in the at least one memory to a first value indicating a negative data quality for at least a portion of the data stored in the at least one datastore.

5. The method of claim **4**, further comprising:

based on determining that the at least one mathematical condition is satisfied, setting the at least one data quality flag in the at least one memory to a second value indicating a positive data quality for the at least one datastore.

6. The method of claim **4**, further comprising:

suspending access of at least one data consuming entity to at least a portion of the data stored in the at least one datastore, based on the at least one data quality flag being set to the first value indicating the negative data quality for at least a portion of the data stored in the at least one datastore.

7. The method of claim **4**, wherein:

the at least one data quality rule further comprises a timing parameter that indicates at least one start time at which to apply the at least one data quality rule; and

the applying of the at least one data quality rule is performed at the at least one start time.

8. The method of claim **4**, wherein the at least one data quality rule further comprises an identification of the at least one datastore to which the at least one data quality rule is to be applied.

9. The method of claim **4**, wherein the sampling parameter specifies the sample amount as a proportion of the data stored in the at least one datastore.

10. The method of claim **4**, wherein the sampling parameter specifies the sample amount as an amount of the data stored in the at least one datastore during a period of time.

11. The method of claim **4**, wherein the historical size of the sample data set comprises a historical average size.

12. The method of claim **4**, wherein the at least one mathematical condition includes at least one condition that a current count of records for which a data attribute stores a particular value is within a predetermined margin of a historical average count of records for which the data attribute stores the particular value, the records being included in the sample data set.

13. One or more non-transitory computer-readable media storing instructions which, when executed, instruct at least one processor to perform actions comprising:

accessing at least one data quality rule stored in at least one memory, the at least one data quality rule being applicable to determine data quality of at least a portion of data stored in at least one datastore, the at least one data quality rule including at least one mathematical condition;

applying the at least one data quality rule to at least the portion of the data stored in the at least one datastore, the applying including:

identifying the at least a portion of the data stored in the at least one datastore;

identifying a first sample data set including a first sample amount of the at least a portion of the data stored in the at least one datastore; and

applying the at least one mathematical condition to the first sample data set to generate one or more results, wherein the at least one mathematical condition includes at least one condition that a current size of the first sample data set is within a predetermined margin of a historical size of the first sample data set; and

based on the one or more results, setting at least one data quality flag in the at least one memory to a first value indicating a first data quality of the at least the portion of the data stored in the at least one datastore.

14. The one or more non-transitory computer-readable media of claim **13**, wherein the first value indicates a negative data quality of the at least the portion of the data stored in the at least one datastore, the actions further comprising:

based on the at least one data quality flag being set to the first value, at least partly suspending access by at least one data consuming entity to the at least one datastore.

15. The one or more non-transitory computer-readable media of claim **13**, wherein the first sample data set includes a random sample of the data stored in the at least one datastore.

16. The one or more non-transitory computer-readable media of claim **13**, wherein the at least one data quality rule further comprises a sampling parameter that indicates the first sample amount.

17. The one or more non-transitory computer-readable media of claim **13**, the actions further comprising:

receiving an indication of a time period in which the at least one data quality rule is to be applied; and

dynamically determining the first sample amount, such that the applying of the at least one data quality rule is substantially completed within the time period.

18. The one or more non-transitory computer-readable media of claim **13**, the actions further comprising:

based on the one or more results, re-applying the at least one data quality rule to the at least one datastore, the re-applying including:

identifying a second sample data set including a second sample amount of the at least a portion of the data stored in the at least one datastore, the second sample amount being different than the first sample amount; and

applying the at least one mathematical condition to the second sample data set to generate one or more additional results; and

based on the one or more additional results, setting the at least one data quality flag to a second value indicating a second data quality of the at least the portion of the data stored in the at least one datastore.

19. The one or more non-transitory computer-readable media of claim **18**, wherein the second sample amount is greater than the first sample amount.

20. The one or more non-transitory computer-readable media of claim **13**, wherein the at least one mathematical condition includes at least one condition that a current size of the first sample data set is within a predetermined margin of a historical average size of the first sample data set.

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